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Prospects for emissions reduction in the UK cement sector

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The UK cement sector was responsible for around 7 Mt of carbon dioxide emissions in 2010. These emissions were due to direct fuel use, the chemical reactions that occur as part of the production process, and electricity use (leading to indirect emissions). Historical trends show that the sector has made considerable reductions in its emissions. This was due to a combination of reduced output, the substitution of emissions-intensive clinker, improved efficiency and fuel switching. The prospects for reductions in the specific energy use and emissions were explored under a range of scenarios out to 2050. Further efficiency improvements were found to be limited. There is potential for additional clinker substitution and fuel switching – although such options are not without their difficulties. The use of carbon capture and storage technology, and alternative (low carbon) cements could lead to larger reductions in specific emissions, but the widescale use of these options is unproven. The approach taken in analysing the cement sector is an example of the bottom-up analysis of the UK industrial sector that has been undertaken in order to produce a database of industrial energy use and improvement potential aimed at meeting the modelling needs of policy makers.

1. Introduction

A detailed, bottom-up database on industrial energy use and improvement potential was developed, in order to assist with whole systems modelling and the requirements of policy makers (Griffin *et al.*, 2013a, 2013b). The UK cement sector was selected as one of five subsectors of industry that were studied in constructing the database. The aim of the current paper is to provide an assessment of the technical opportunities to reduce energy use and carbon dioxide (CO₂) emissions within the UK cement sector. In this regard, the specific objectives are to define current energy use and CO₂ emissions, with particular reference to physical flows of materials; to examine how the output, energy use and emissions of the sector have evolved over time; and to discuss the prospects for various technological improvement opportunities within a number of future scenarios. The present work offers both an assessment of the cement sector, and serves as an illustration of the approach taken in constructing the broader industrial database.

2. Background and trends analysis

The cement sector is relatively simple and homogeneous, in terms of the product manufactured and its energy-using processes. Although it is small in terms of economic output, it is highly energy and carbon intensive. The vast majority of cement manufacture in the UK is of the form ‘calcium silicate’, more

commonly referred to as ordinary Portland cement (OPC). Almost all cement is manufactured for use as concrete, for construction purposes.

The production steps of the dry process route are shown in Figure 1. Variants on the process occur in the kiln, which can be classified as wet, semi-wet, semi-dry or dry. These variations involve adding water to the raw materials, which allows easier grinding and the use of different technologies in the preheating process. This water needs to be removed through a combination of filtering and evaporative drying at a later stage in the process, however, which has an energy requirement. The dry production route is generally the most energy efficient. The kilns usually include a number of stages for preheating of the raw materials and ‘precalcining’, both of which improve efficiency. In all production routes the energy use and emissions are dominated by the kiln. The kiln produces clinker, which is then ground with other materials to create cement. A more complete description of the production process can be found in the literature (e.g. Choate, 2003; CSI and ECRA, 2009; European Commission, 2010; IEA, 2009a; Norman, 2013). As of the end of 2011 the UK had 14 cement kilns located at 12 sites; four kilns having closed during the period 2008–2009. There are 11 dry kilns (representing 76% of capacity), three semi-dry kilns (representing 11% of capacity) and a single semi-wet kiln (representing 13% of

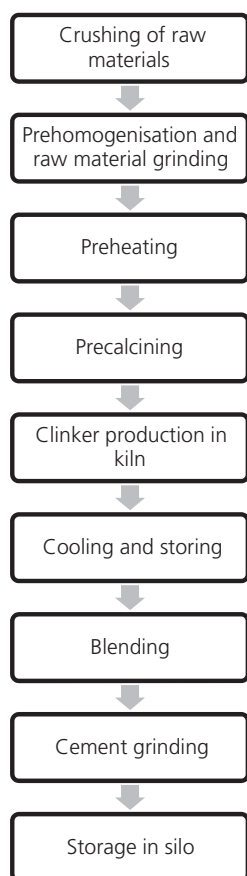


Figure 1. Stages of cement production. The dry production route, utilising both preheating and precalcining is represented. Source: Reproduced from Norman (2013)

capacity) (D. Edwards, Mineral Products Association, private communication, 20 November 2011).

2.1 Carbon dioxide emissions

The emissions from the UK cement sector are shown in Figure 2. These were based on data from the Cement Sustainability Initiative's 'Getting the Numbers Right' project (CSI, 2013), supplemented by the authors' calculations in separating the source of emissions and accounting for emissions from biomass and electricity. An emissions factor of 110 kgCO₂/GJ was used for biomass (the IPCC default for solid biomass). Emissions factors for electricity were based on UK grid averages (AEA, 2012). When examining these data it should be noted that values for 1990 and 2000 were based on historic estimates. In contrast, the figures for 2005 onwards were based on the collection of plant data, and are therefore expected to be of greater accuracy (CSI, 2009). The sources of emissions in Figure 2 are as follows.

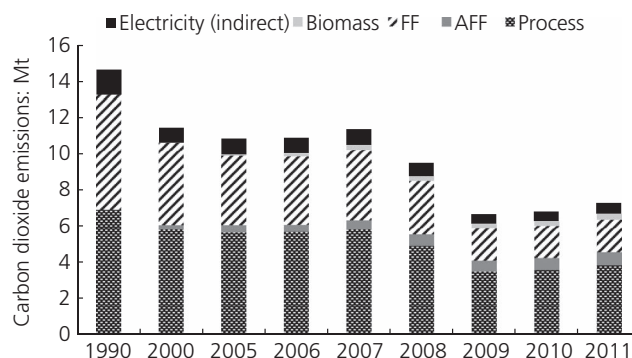


Figure 2. Emissions from UK cement manufacture, 1990–2011. AFF, alternative fossil fuel; FF, fossil fuel. Source: Data extracted from CSI (2013), plus the authors' calculations as described in the text

- Process emissions: carbon dioxide is released in producing clinker from calcium carbonate (usually limestone) within the cement kiln.
- Direct fuel use: this consists of fossil fuels (mainly coal, with smaller quantities of petroleum coke, fuel oil, diesel oil and natural gas), alternative fossil fuels (mainly road transport vehicle tyres and other wastes) and biomass (mainly waste from sewage and animal products). Fuel is primarily used to provide high temperatures in the kiln.
- Indirect emissions from electricity demand: electricity is primarily required for grinding and mixing at various stages of manufacture, all electricity is purchased from the national grid.

It should be noted that under some accounting systems biomass and alternative fossil fuel emissions may not be included in the sector totals, for example see CSI (2009). It can be seen in Figure 2 that over the period 1990–2011 carbon dioxide emissions from the UK cement sector have approximately halved. The factors contributing to this reduction are examined in Sections 2.2 and 2.3.

2.2 Production levels

Cement production between 1990 and 2011 is represented in Figure 3, the number of plants producing both cement and clinker are also shown (note that although there are 12 clinker plants, there is a total of 14 kilns at these plants). These data were taken from CSI (2013). The total cement production includes a number of components.

- Clinker: the most energy- and emissions-intensive part of cement manufacture.
- Mineral components and gypsum (including clinker substitution): additives are used to influence the cement

properties and to reduce its emissions intensity, by substituting for clinker.

- Cement substitutes: substitutes for cement can be employed when producing concrete. This reduces the amount of emissions-intensive clinker required.
- Clinker imports and exports: these are generally low. For all years, except 2000, there are net imports. The relatively low cost of cement makes it uneconomic to transport more than 200–300 km by land (European Commission, 2010), although a seaport or rail link located near a plant can increase trade.

Several trends are noted in Figure 3. Production was affected by the global economic slowdown from 2007 to 2009, and has not yet returned to pre-recession levels. In 2010 the sector ran at just 61% of capacity (based on the production shown in Figure 3 and capacities reported by www.cementkilns.co.uk). Before the period of recession total output was fairly stable. The ratio of clinker to cement materials (including cement substitutes) has decreased from 93% in 1990 to 73% in 2011.

2.3 Specific energy use and emissions

Figure 4 shows the specific energy requirement and specific emissions of both clinker production and cement production from 1990 to 2011. This was based on data from CSI (2013) and the authors' own calculations in summing the sources of energy and emissions and using output data to obtain specific metrics. Electricity demand is included in measures related to cement but not clinker. Biomass is assumed carbon neutral in these results. Energy is shown in terms of 'gross calorific value' (as is used throughout this work, 'higher heating value' is the terminology preferred in North America). Some trends to note from Figure 4 are as follows.

- The specific energy and emissions have displayed a fairly uniform reduction over the period.

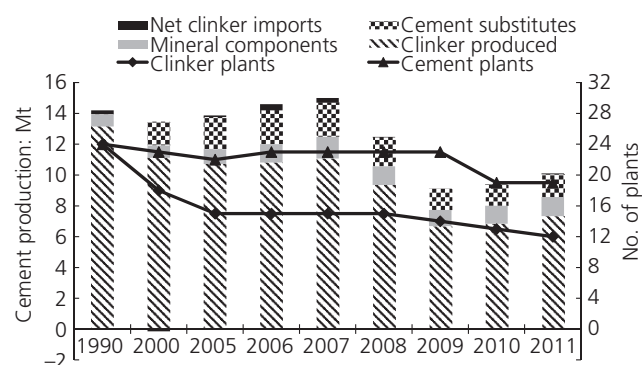


Figure 3. UK cement production, and producing plants, 1990–2011. Source: Data extracted from CSI (2013)

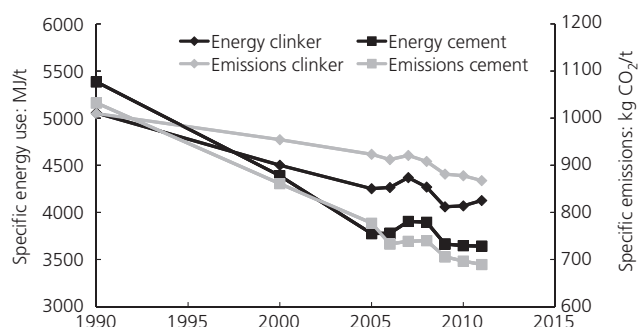


Figure 4. Specific energy use and specific emissions of UK cement production. Note the axis truncation. Source: Data extracted from CSI (2013), plus the authors' calculations as described in the text

- Specific energy and emissions measures related to cement products have shown greater relative reductions than those related to clinker alone. This is due to the reduction of clinker content in cement, as discussed above.
- Instantaneous energy efficiency will be better than that shown here, which includes 'start-ups' and 'shut-downs'.

The energy required in clinker production was further examined over the longer term. Information on the physical output of different kiln types in the UK, and their specific energy requirements, between 1973 and 2010, was extracted from an online source of information on individual kilns (www.cementkilns.co.uk). These data were aggregated to represent the situation in the UK cement sector. While this method may not accurately represent year-to-year fluctuations in production it should be sufficient to capture trends. Index decomposition analysis, using the logarithmic mean Divisia index I method (Ang *et al.*, 1998; Hammond and Norman, 2012) was used to analyse the trends in kiln energy use. The results are shown in Figure 5; changes in kiln energy demand are assigned to three effects

- change in clinker output
- process substitution: switching between dry, semi-dry, semi-wet and wet kiln technologies
- change in energy intensity of the different kiln technologies.

A 65% reduction in kiln energy demand over the period examined was dominated by falls in output, accounting for over half the change seen. This fall in clinker output could be the result of either a reduction in the output of cement, or due to the substitution of clinker in cement production with less energy-intensive alternatives. It can be assumed that until 1990 the fall in clinker output was driven by a fall in cement output, as the clinker content of cement remained high up to this date. Since 1990 there has been a fall in the clinker content of

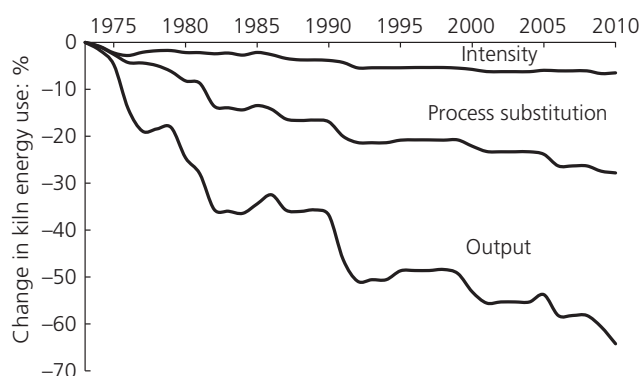


Figure 5. Trends in kiln energy use 1973–2010, shown as a percentage change from 1973. Decomposition analysis separates the effects of changes in energy intensity, process substitution and output. Source: Data extracted from www.cementkilns.co.uk, plus the authors' calculations as described in the text

cement, with reductions in cement output having an effect from 2007 (see Figure 3).

Based on the data shown in Figure 5, the overall energy use per unit of clinker production improved by 37% between 1973 and 2010. This was predominantly driven by changes in production away from wet kilns (process substitution), rather than improvements in the energy efficiency of the different kiln types (represented by the energy intensity effect). Improvements in the efficiency of kilns have slowed over more recent time periods (see Figure 5). This could indicate that the limits of efficiency for such kilns are being reached. Dry kilns now dominate UK production, and therefore further potential for reducing energy demand through process substitution is limited.

3. Technological improvement potential

3.1 Background

Improvement potential in the sector, through a number of existing and future technologies perceived as having a role in energy demand and emissions reduction to 2050, was explored. The identified technologies and measures fit into five categories.

- **Energy efficiency:** this includes retrofit kiln technologies (process improvement) and kiln replacement (process substitution). The installation of a precalciner and additional preheater stages were identified as process improvements to some dry kilns, while semi-wet and semi-dry kiln capacity may be replaced by the 'best practice' dry rotary kiln or fluidised bed technology. Grinding technology improvements were not included here, as it was not possible to determine what baseline technologies were in place.

- **Fuel switching:** the displacement of fossil fuel (predominantly coal) use in clinker production with waste or biomass.
- **Clinker substitution:** this involves the reduction of clinker production per unit of cement by substituting for other materials, typically pulverised fly ash or ground granulated blast furnace slag. Such measures include clinker substitution at the stage of concrete production.
- **Carbon capture and storage (CCS):** this relates to the possible future application of CCS technologies. These technologies reduce carbon dioxide emissions at the cost of increasing energy demand (Hammond, 2013; Hammond *et al.*, 2011). Post-combustion CCS with monoethanolamine solvent scrubbing and an 85% capture rate was the specific technology modelled here (IEA GHG, 2008). Oxycombustion capture technology is also being developed for the sector and is likely to require less energy demand, but its application to the kiln is less certain (ECRA, 2012). Post-combustion capture technology requires significant heat demand (Hammond *et al.*, 2011; IEA GHG, 2008) that is here assumed to be met by an auxiliary combined heat and power (CHP), the emissions from which must also be captured to make this option viable. It should also be noted that the capture rate adopted here only applies to the operational or 'stack' emissions and does not account for so-called 'upstream emissions', see Hammond and O'Grady (2014) and Hammond (2013) for further discussion.
- **Cement substitution:** the future replacement of OPC by any of a group of identified emerging 'low-carbon dioxide' cements. These include Novacem, E-Crete, Celitement and Aether (Net Balance Foundation, 2007; Stemmermann *et al.*, 2010; Velandia *et al.*, 2011; Walenta, 2011).

3.2 Scenario definition

The identified improvement technologies for the UK are incorporated into a technology framework through which further scenarios may be designed and evaluated in detail. The baseline year for the framework was taken as 2010; full details of the both the 2010 baseline and the technologies are included in an online database (Griffin *et al.*, 2013a, 2013b). Four future scenarios are presented in order to demonstrate this approach. The cement industry has been active in the area of technology roadmapping both at the global and UK level (IEA, 2009b; MPA, 2013), these roadmaps were drawn on in constructing the scenarios detailed below and are summarised in Table 1.

- **Low action:** this scenario describes a path of only slight improvements. No further investment is made in additional process technology improvements and kiln efficiency is only improved incidentally through the replacement of retired kilns. Substitution of fossil fuels with waste alternatives is limited to 50%. As clinker substitution influences product

	2020	2030	2050
LA	Semi-dry kilns replaced with best practice dry kiln	Semi-wet kiln replaced with best practice dry kiln; other dry kiln replacements continue	50% Waste as kiln fuel, half of which is biomass; 30% clinker substitution
RA	As LA, plus precalciners and preheater stages added to existing dry kilns	As LA	80% Waste as kiln fuel, half of which is biomass; 35% clinker substitution; 5% of market to alternative cements
RA-CCS	As RA	As LA	As RA, plus 40% of capacity has CCS
RT	As RA	As LA	33% Capacity from fluidised bed kilns; 90% waste as kiln fuel, 75% of which is biomass; 40% clinker substitution; 33% market to alternative cements

LA, low action; RA, reasonable action; RA-CCS, reasonable action with carbon capture and storage; RT, radical transition

Table 1. Details of the future scenarios analysed for the UK cement sector

- quality and is already undertaken to a reasonable degree, further substitution is limited to a few per cent. Alternative cements have negligible impact on the market for OPC.
- Reasonable action: all identified efficiency technologies are installed by 2025 and retired kilns are replaced with best-practice rotary kilns by 2030. Clinker substitution reaches 35% and waste fuel use in the kiln reaches 80% by 2050, half of which is biomass. These proportions reflect substitution levels assumed in the International Energy Agency roadmap (IEA, 2009b) and the Mineral Products Association roadmap (MPA, 2013), respectively. Alternative cements capture 5% of the market for OPC.
 - Reasonable action including CCS (RA-CCS): this scenario is based on reasonable action, but includes CCS. The latter is installed at 40% of cement manufacturing capacity. This is considered ambitious, given the economics of transporting carbon and the location of most UK cement plants. The projections also presume the option of using biomass in the CHP plant, which accompanies the capture technology. Biomass co-firing with CCS may, of course, mitigate upstream emissions on a full lifecycle basis, due to potential ‘negative emissions’ (Kruger and Darton, 2013; Hammond and O’Grady, 2014); something that needs careful study in the future.
 - Radical transition: this scenario explores a boosted version of the reasonable action (without CCS) scenario. All identified kiln equipment and replacement technologies are taken up as before, except a third of dry rotary kiln capacity is replaced with fluidised bed kiln technology by 2050. Kilns are fuelled by 90% waste fuels of which 75% is biomass. Still limited by implications on product quality, clinker substitution reaches 40%. Low-carbon dioxide cements capture 33% of the OPC

market by 2050. The performance of these alternative cements is based on the average performance of the four aforementioned variants. This scenario also considers the impact of measures excluding alternative cements.

Fuel and clinker substitution are projected to increase linearly from 2010, whereas the uptake of long-term options (fluidised bed kilns, alternative cements and CCS) are taken to increase linearly from 2030. In reality, due to the small number of kilns the uptake would involve a number of discrete steps. The representation here should therefore be viewed as the average situation. The carbon intensity of electricity generation is not assumed to improve over the period of the scenarios. This is a simplification; however, electricity demand only accounts for a small proportion of the cement sector’s emissions (see Figure 2).

3.3 Projections

Figure 6 shows the effect of each of the scenarios defined above in influencing the specific energy demand, and specific emissions, of cement production in the UK. In calculating specific emissions biomass is considered carbon neutral, the emissions from the combustion of non-biomass waste (alternative fossil fuel) are included. A more favourable accounting of emissions from waste would therefore produce a greater reduction in emissions where they are used. In Figure 6 each trajectory is the cumulative effect of the implemented measures in the order in which they are listed. The trajectories also represent the interactive effect of all measures applied in the scenario such that the conflicts and synergies between them are accounted for. The exception to this is in Figure 6(g) and (h), where two sub-scenarios that are not compatible are represented. As the adoption of alternative

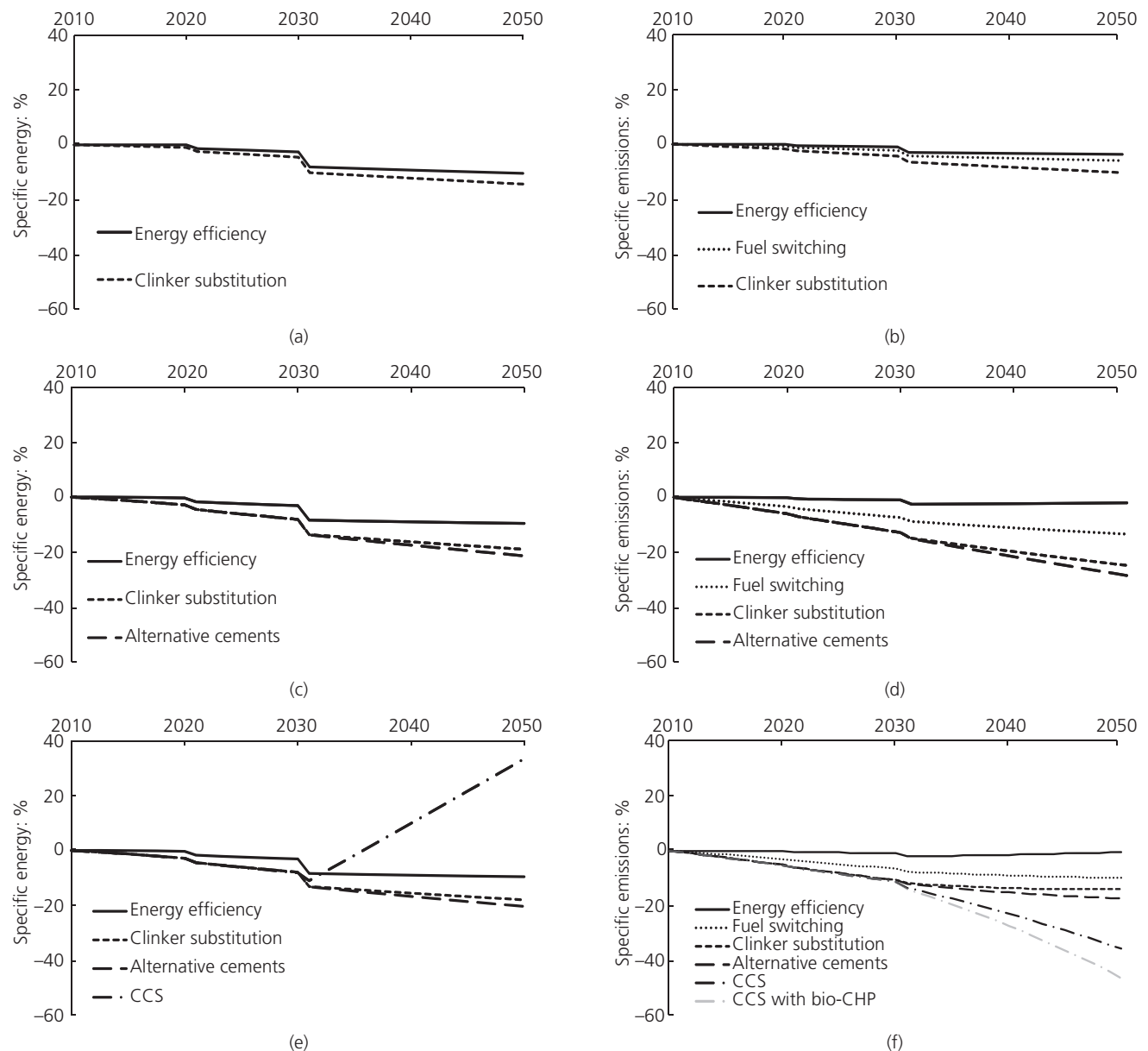


Figure 6. Future specific energy demand and emissions of the UK cement sector; projected with the aid of alternative scenarios. (a) specific energy demand (low action; LA); (b) specific greenhouse gas (GHG) emissions (LA); (c) specific energy demand (reasonable action; RA); (d) specific GHG emissions (RA);

(e) specific energy demand (RA with carbon capture and storage; CCS); (f) specific GHG emissions (RA-CCS); CHP, combined heat and power; (g) specific energy demand (radical transition; RT); (h) specific GHG emissions (RT); AC, alternative cement. (Scenarios are defined in Table 1) (continued on next page)

cements limits the impact of measures that apply to OPC production 'Clinker substitution non-AC' represents the case in which the measures up to clinker substitution are adopted, with no alternative cement production.

It can be seen that there is little improvement expected from further efficiency measures, even if fluidised bed kilns are

partially taken up. In both of the radical (or optimistic) scenarios, RA-CCS and radical transition, the maximum reduction in specific emissions is about 50% from the 2010 level or just below 80% from the 1990 level. However, if additional biomass is not made available for the CHP at the CCS equipped plant, then RA-CCS reduces specific sector emissions by just over 40%. This presents only a marginal

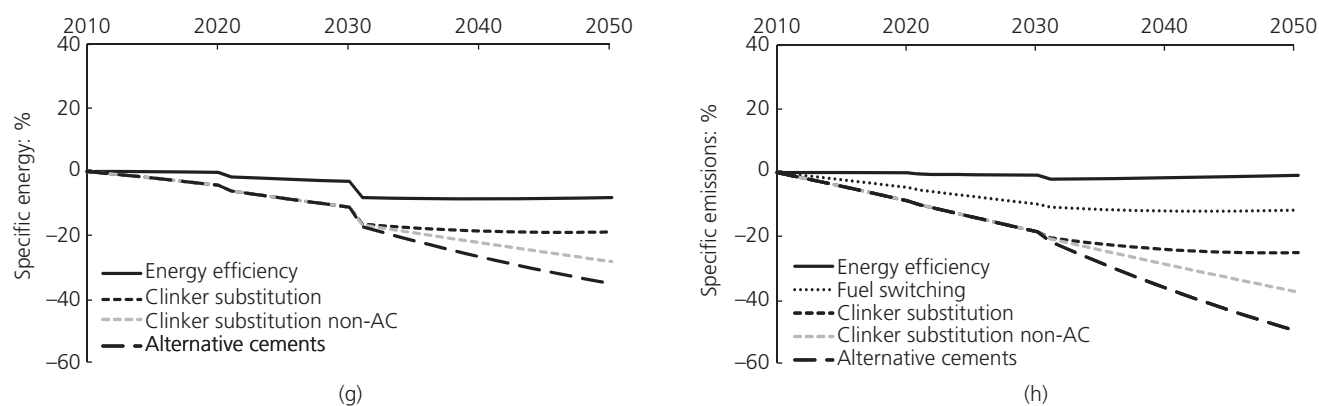


Figure 6. Continued

improvement on the radical transition scenario without alternative cements, indicating that biomass should be used to fuel the CHP plant required for CCS adoption, if a 40% penetration of post-combustion capture technology is to be worthwhile.

As the different technologies interact they can reduce the influence of each other. For example, clinker substitution will reduce the influence of energy efficiency and fuel switching. CCS technology has an 85% capture rate regardless of how much carbon dioxide results from combustion or calcination (but see the note about the impact of ‘upstream emissions’ above). Therefore, where CCS is deployed, any reduction in on-site emissions from efficiency, fuel switching and clinker substitution is mostly negated. In the case of biomass use with CCS, if biomass is assumed carbon dioxide neutral, cement manufacture can become carbon dioxide negative (Kruger and Darton, 2013). Perversely, conflict then arises with clinker substitution in that reducing kiln activity would deny the opportunity of CCS to take carbon out of the atmosphere. It would therefore be useful for such a plant to focus on supplying the high clinker OPC market.

Production of alternative cements is considered incompatible with carbon capture, as such cements would reduce site emissions to a level at which CCS is unlikely to be economically viable. CCS is therefore viewed as applying to the part of production that would not be substituted by alternative cements. CCS may have an effect in changing the market for OPC and alternative cements. Although CCS is unlikely to compete with alternative cements on price, the prospect of capturing emissions for any grade of OPC could act as a laggard to reforming construction industry standards for a greater acceptance of alternative cements. These effects are exogenous to the projections but, as with any other external

factor, may be adjusted for by the choice of uptake levels inputted by the user.

There are additional efficiency potentials not included here, either due to a lack of information (e.g. grinding technologies), or because they offer little potential. For example, the use of organic Rankine cycles to generate electricity from waste heat in the UK cement sector could generate around 9–26% of the sector’s electricity demand, but this would reduce emissions by only 0.8–2.3% (Norman, 2013).

4. Discussion

The trends in historical improvement and those expected through technological change show decreasing advances being made through efficiency. This is characteristic of ‘energy-intensive’ manufacturing, in which high energy prices (energy costs typically represent 40% of operational costs for a cement manufacturer (European Commission, 2010)) have led to easier efficiency improvements being realised, leaving little potential for further improvement without more radical change (Hammond and Norman, 2012). Production capacity in the sector is owned by a small number of companies, which has allowed for significant rationalisation of capacity from a large number of small wet kilns to a small number of large dry kilns. Over recent years the sector has been under pressure to reduce emissions in contributing to national emissions reductions. The sector is involved in the EU Emission Trading System, which was launched in 2005, and the Climate Change Agreements since 2001. All members of the Mineral Products Association are signatories or supporters of the ‘Agenda for Action’ of the CSI (2002), which was established by cement producers worldwide in conjunction with the World Business Council for Sustainable Development. A ‘sector plan’ was also developed with the Environment Agency in 2005, requiring the industry to meet a number of specific sustainable objectives. Roadmaps, as drawn on above, have been developed,

with the sector's 'carbon strategy', first published in 2005, the sector has since envisioned an 80% reduction in greenhouse gas emissions by 2050 (MPA, 2013).

Cement kilns are well suited for the disposal of waste fuels, as the mineral content in such fuels is incorporated into the clinker, and therefore no residual ash or heavy metal disposal is required, as would be the case if disposal was by means of an incinerator (CSI, 2009). Figure 2 shows a historic shift towards waste fuels and biomass. The notable increase in fuel switching to waste fuels, including biomass waste, since 2000 has been incentivised in part by the 1999 EU landfill directive and other international agreements made by the UK to reduce wastes to landfill and increase the recovery of energy (Taylor, 2013). The use of these fuels helps to meet emissions targets and switching to them is likely to continue to some extent, as discussed in the scenarios above. The availability of suitable fuels may act as a key constraint here. The sector would have to compete for supplies of biomass with other sectors, such as electricity generation. The level of savings offered through the use of biomass is also an issue of contention. In addition, if it is possible to eliminate or reduce the wastes that supply cement kilns (for example retreading tyres rather than combusting them) this may be preferable from the wider perspective of the UK's emissions.

Clinker substitution has already been widely adopted in the UK to reduce the carbon intensity of cement, the same drivers and policies discussed above in reference to energy efficiency are relevant here. Clinker substitution could continue to increase somewhat without adversely affecting the properties of cement (up to a maximum of 40%, from the current level of 31% (CSI, 2013)). The main clinker substitutes in the UK rely on carbon-intensive industries, blast furnaces and coal-fuelled electricity generation. Whether these operations continue in the UK over the long term, when the national focus is likely to be on a decarbonisation strategy, could influence the availability of economic clinker substitutes.

CCS holds strong potential for emissions reduction in the cement sector, due to its ability also to influence process emissions, which are unaffected by energy efficiency or fuel substitution. However, CCS is, as yet, an unproven technology on a large scale (Hammond *et al.*, 2011). To be attractive for CCS a cement kiln should be of high capacity (4000–5000 t/d (IEA, 2009b)). Currently, only a single kiln in Rugby meets this requirement in the UK. This site is located inland, far from likely CCS hubs centred around storage options in the North or Irish Seas (DECC, 2012; Element Energy, 2010). The adoption of CCS is therefore considered speculative.

The uptake of cement alternatives is also considered speculative. OPC is well established, having a mature supply chain

and being well understood for use in construction. The construction industry is characteristically wary about unfamiliar products, and Europe is more restricted by way of regulations than other markets, such as China and Australia (Von Weizacker *et al.*, 2009). Existing EU and US standards have essentially been shaped by Portland cement and concrete manufacturing bodies for over a century, being prescriptive in nature (Duxson and Provis, 2008). Shifting to a standard based on the performance of the material would remove a barrier to the adoption of alternative cements. Despite various sources presenting alternative cements as the optimal pathway (e.g. Croezen and Korteland, 2010 and Von Weizacker *et al.*, 2009), they appear a less serious pathway in the industry's carbon strategies (IEA, 2009b; MPA, 2013). It is clear that the Portland cement industry intends to stay in business into the long term with the aim of supplying well tested, familiar products to the construction industry (Taylor, 2011).

Although there is little import and export of cement, UK production is dominated by international companies, and the production process is fairly uniform at a global level. The successful adoption of technologies (especially CCS or alternative cements) outside the UK would act as a strong driver for change in the sector here. Similarly, the adoption of these technologies within the UK would drive change internationally.

The results shown in Figure 6 are presented in 'specific' terms; that is, per tonne of cement output. Variations in the level of output could therefore have a considerable effect on the absolute energy use and emissions of the sector. Estimating future demand for cement was outside the scope of this work. Demand is primarily driven by construction activity. It is noted that opportunities to use less cement in providing the same structural service could provide reductions in the energy demand and emissions of the sector (Allwood and Cullen, 2011; Orr *et al.*, 2011).

5. Conclusion

The UK cement sector has made reductions in its emissions per unit of cement over the past two decades, due to clinker substitution, fuel switching and efficiency improvements. This has largely been driven by energy costs and policy. Making substantial reductions in specific emissions out to 2050, as is required by emissions reduction targets, will require measures that go beyond this, incorporating CCS technology and the adoption of alternative cement formulations. Both of these options are open to considerable uncertainty, and will probably require considerable support from both the industry and government policy to be realised. Reductions in output from the sector have reduced emissions historically, and continuing this trend, through the more efficient use of cement, also holds potential. The sector faces a considerable challenge

in contributing to carbon reductions over the longer term, and a similar situation exists in many energy-intensive industries.

Cement was one of a number of subsectors that were examined by means of detailed, bottom-up research, in order to develop a usable energy database on the UK industrial sector. The approach taken here, of defining the energy use and emissions in relation to physical output, and then of assessing the technologies that could be applied to this baseline, is replicated across the other subsectors. This bottom-up approach provides the flexibility to construct detailed forecasting assessments. It is anticipated that this will help meet the needs of policy makers (such as those at the UK Government's Committee on Climate Change and the Department of Energy and Climate Change) for better estimates of the potential for industrial energy demand and carbon dioxide emissions reduction going forward. Within the full database cost information is also included, so the information can be utilised by economic, whole systems models, such as UK Times.

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